# AN INVESTIGATION OF WINTER WEATHER TYPES OF THE WESTERN NORTH ATLANTIC OCEAN AND THEIR RELATION TO THE NORTH AMERICAN ZONAL INDEX

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of the Western North Atlantic Ocean and their Relation to
The North American Zonal Index

by

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# I. INTRODUCTION

The purpose of this paper is (1) to extend the investigations made in a previous paper by Lieutenant Lackner and Lieutenant Stone in which an attempt was made to forecast the weather conditions over the North Atlantic from synoptic reports received from the North American continent only, and (2) to make further contributions of forecasting methods based on the methods outlined in their paper.

The work of Lackner and Stone was confined to winter months for the reason that it is only during this period that pressure systems are consistently strongly defined and consequent air flows definite. Likewise, the winter months are the period of roughest conditions, except for hurricanes, and consequently the period most difficult for forecasting. The area concerned was along the Atlantic Coast, from Newfoundland to Florida and six hundred miles to seaward. By recognizing recurring weather patterns over this area and the eastern part of North America, they were able to classify them into six weather types. Then, dividing the area into five-degree squares, they made tables showing the percentage of cloudiness, average winds and average weather for each square when a given type exists. Of the maps examined, 56% were classified under the types; the remaining 44% were unclassifiable.

The principle objective in this paper will be that of finding a means of forecasting the occurrence of the weather types. Dr. Rossby and collaborators have shown that there is a definite relationship between the zonal index and the general circulation pattern. If it can be shown statistically that there is some correlation between a zonal index available from the North American continent and weather types, then there is a means to extend the usefulness of the methods outlined by Lackner and Stone.

## II. THE GENERAL CIRCULATION

A thorough understanding of the thermodynamic and dynamic processes of the atmosphere is necessary in order to understand and predict weather processes. This is especially important when an attempt is made to extend a forecast over long periods of time or into areas from which one receives no reports. Improvements can be made only as more is learned of the general circulation of the earth's atmosphere and of its causes.

In conjunction with the development of the five-day forecasting project at M. I. T., Rossby and his collaborators have made marked progress in theorizing the causes of the General Circulation. A general knowledge of this work is necessary for an understanding of the significance of the Zonal Index.

A brief summary of the theory follows:

For a perfectly smooth, homogeneous, non-rotating earth receiving heat from the sun with a maximum at the equator decreasing to a minimum at the poles, a simple meridional circulation would result. This would cause the heated equatorial air to rise and the relatively cool polar air to sink, resulting in a pressure gradient toward the poles at upper levels and toward the equator at the surface. The resulting path of air particles in this circulation would then be: rising at the equator, northward flow at upper levels, sinking at the poles and southward flow along the surface to the equator.

When the earth is set in rotation about its axis and surface friction brought into play, the above described circulation would break down as shown in Plate I. First, the deflecting force due to the earth's rotation would cause horizontal flowing particles to be deflected toward the right (in the northern hemisphere) resulting in a westerly component aloft and an easterly component at the surface (Figure A). The westerly wind aloft would be brought down at the poles and the easterly surface winds would be projected up at the equator because of the inertia effect of the earth's rotation (Figure B). The pressure distribution must adapt itself to this motion. This will cause a sea level pressure maximum between the westerly and easterly surface components in Figure

B. Under the influence of the pressure built up to the south, surface winds near the poles will be frictionally retarded, which will cause this stream to turn northward again (Figure C). As the air at the pole continues to cool and sink, this returning air must be forced aloft, thereby establishing the cellular circulation shown in Figure D.

Let us now consider the energy which maintains each cell. The equatorial and polar cells have cyclonic or counter-clockwise circulation (looking eastward) and may be called direct cells as they carry heat from warm to cold source, thereby transforming the potential energy of heat difference into the kinetic energy of the air particles. The central cell with anticyclonic or clockwise circulation (looking eastward) receives its energy from the viscous drag of the two direct cells. In other words, the strong westerly winds of the adjacent direct cells create eddies with approximately vertical axes. Through the action of these eddies, the momentum of the westerlies is transferred throughout the central cell. The excess of centrifugal force acting on the west winds of middle latitudes, forces the air southward, but equilibrium is never reached, since the air still further to the south, instead of piling up and thus permitting the establishment of an adequate cross-current pressure drop, cools through radiation and sinks to lower levels where it acquires a northward movement.

The pressure difference observed at the surface is a reflection of the velocities of the frictionally driven westerlies in this central cell. Consequently, it follows that the pressure difference between the limits of the westerlies must give a good indication of the relative strength of the westerlies.

A profile of the mean meridional pressure distribution around the earth can be obtained by summing the pressure values around a latitude circle from sea level pressure maps. This was done for daily, monthly, and annual pressure means, and it was found that the minimum and the maximum in the mean profiles lay at nearly $55^{\circ}$ North and $35^{\circ}$ North respectively. The difference between the means of the pressures about the $35^{\circ}$ North and $55^{\circ}$ North latitude circles was taken as an indication of the strength of the westerlies, and it has been called the Zonal Index.

From the theorem of the conservation of absolute vorticity, Rossby has shown that the westerly winds have stable characteristics. That is, when they are disturbed by thermal or frictional changes upon crossing continental coast lines, they maintain their general easterly flow but with sinusoidal paths. These patterns show up on high level pressure charts.

It has been shown that the following relation holds:

$$C = U\left(1 - \frac{L^2}{L_S^2}\right)$$

Where: C = eastward velocity of the perturbation (trough or wedge).

U = velocity of the zonal westerly wind.

L = wave length of the perturbation.

$L_s$ = wave length of the perturbation for which C is zero (standing wave length).

$L_s = 2\pi\sqrt{\frac{UR}{2\Omega \cos \phi}}$ Where R = Radius of the earth.

$\Omega$ = angular velocity of the earth, and $\phi$ = the latitude.

It also has been shown that the number (N) of such perturbations is: $N = \sqrt{\frac{2\Omega R \cos^3 \phi}{U-C}}$

Since these theoretical considerations show that the number of perturbations in middle latitudes and the rate of their movement are functions of the intensity of the westerly winds, it follows that there must be a close relationship between weather patterns with their surface pressure changes and distribution and the Zonal Index which, as mentioned above, is a measure of the intensity of the westerlies.

## III. THE ZONAL INDEX

As described above, the Zonal Index is the average pressure about the 55° North latitude circle subtracted from the

average pressure about the $35^{\circ}$ North latitude circle. In computing the index, the isobars are first drawn from all available reports. The pressure value for each ten degrees of longitude is then picked off from the map and tabulated and summed for the $35^{\circ}$ latitude circle. This procedure is then repeated for the $55^{\circ}$ latitude circle. The sum from the $55^{\circ}$ latitude circle is then subtracted from the sum from the $35^{\circ}$ latitude circle and the difference divided by the number of pressure readings used along the latitude circles.

If desired, the Zonal Index may be subdivided into partial indices which will show the index just between certain specified longitudes. In this paper, two partial indices were used, one between $60^{\circ}$ West and $120^{\circ}$ West longitude, called the "Continental Index" and the other between $60^{\circ}$ West and $180^{\circ}$ West longitude, called the "Continental-Pacific Index". The Continental Index can be accurately established from reports from the United States and Canada. The Continental-Pacific Index, however, has to depend on reports available from the Pacific which may not be forthcoming during wartime. A reasonably accurate index can be computed, however, by means of observations from Pearl Harbor, Midway, Dutch Harbor, Kanaga, and Sitka in conjunction with the continental reports.

As the Continental-Pacific Index is more extensive, it is assumed that it is the best index to indicate weather types.

As this has a high correlation factor with the Continental Index (.820), either may be used with practically equivalent results.

From computation of daily values of the indices, it was noted that the trend of the values was quite regular, but the day-to-day variation was so great that a more or less saw-toothed curve resulted. It was therefore decided to use five-day mean values, a procedure followed by the long-range forecasting group at M. I. T. All index values used in this paper are of the five-day running mean type; that is, the average of the value for the present day and the four preceding days. This practice tends to minimize the influence on the index of individual migrating pressure centers and thereby gives more weight to the intensity, position, and changes of the quasi-permanent centers.

## IV. THE WEATHER TYPES

Lackner and Stone arrived at weather type-classification by examining surface maps for October 1938 through March 1939 plus the Deutsche Seewarte synoptic maps for the polar year 1932-33. In general, they grouped the maps into good and bad weather patterns for the area along the East Coast extending from 600 miles eastward of Florida to Newfoundland. The types determined in their work are reproduced in Plates II to IV.

Below are given the criteria for each type as defined by them.

(1) Bad Weather Types:

Type $A_1$

Referring to the photostat containing type $A_1$, the following three centers of action are noted: (1) a low on the northeastern coast, moving gradually toward Newfoundland; (2) a high pressure cell starting to build up over Georgia and the Carolinas and proceeding in the wake of the above low; (3) a high pressure area entering the United States from Canada over the Great Lakes region and moving to the southeast.

Type $A_2$

Centers of action: (1) a filling cyclone well up in Newfoundland region with the Atlantic polar front paralleling the coast and quasi-stationary; (2) a series of waves developing and travelling along the front; (3) an elongated high with NE-SW axis and extending from Canada over the Great Lakes into the southern states; (4) the Bermuda High well established to the east of the front.

Type $A_3$

Centers of action: (1) an intense low at sea paralleling the coast; (2) a high pressure area entering the United States from the middle of Canada building up to the rear of the low and moving rapidly toward the coast.

Type B

This type consists essentially of: (1) an elongated high pressure area with a NE-SW axis and extending from Texas to Newfoundland; (2) an intense low off the coast proceeding northeastwards but having its path blocked by the northern portion of the high pressure mentioned in (1); (3) a weak cyclonic activity between the high over the eastern states and the high pressure area over the Rocky Mountain states.

Type C

Centers of action consist of: (1) a well-developed low pressure in the Nova Scotia area; (2) a high pressure area entering the United States over the Great Lakes region and travelling southeast; (3) a high pressure area over Alabama, Georgia, and the Carolinas and moving eastward; (4) a well marked front between the two highs with wave developments proceeding along it toward the low in the northeast.

(2) Good Weather Types:

Type D

This type consists of: (1) an old low pressure center in the Nova Scotia-Newfoundland area; (2) a high pressure cell with N-S axis extending from the Great Lakes to the Gulf states and moving steadily eastward; (3) a weak high pressure system over the West Coast; (4) a low pressure development on the northwest side of the high mentioned in (2) and

with a front from the low separating the two high pressure areas.

Lackner and Stone did not include a table giving dates of occurrence of types, so the authors had to spend considerable time in examining charts to obtain such a table. This is shown in Table "A" and includes the results of examinations of the Deutsche Seewarte charts for the polar year 1932-33, the charts from January 1 to March 13, 1939 (charts for November and December 1938 being available), and the charts from November 20, 1940 to February 23, 1941. The authors identified 141 types out of 250 cases giving a percentage of 56.4%. This percentage is exactly that found by Lackner and Stone. However, identical results are misleading, for, a comparison of the tables of frequencies and persistencies as found by the authors (Table "C") with those listed by Lackner and Stone (Table "D") show that a large latitude must be allowed for the personal factor involved in the identification of a given pressure distribution with the more or less rigid patters defined in the types.

A variation of type "C" is suggested by the authors which retains on the whole the same characteristics as defined by Lackner and Stone. This would occur as a transition from type C when the high over Alabama, Georgia, and the

with a front from the low separating the two high pressure areas.

Lechner and Stone did not include a table giving dates of occurrence of types, so the authors had to spend considerable time in examining charts to obtain such a table. This is shown in Table "E" and includes the results of examinations of the Deutsche Seewarte charts for the polar year 1932-33, the charts from January 1 to March 13, 1939 (charts for November and December 1938 being available), and the charts from November 20, 1940 to February 28, 1941. The authors identified 111 types out of 150 cases giving a percentage of 74.0%. This percentage is exactly that found by Lechner and Stone. However, identical results are misleading; for, a comparison of the tables of frequencies and persistencies as found by the authors (Table "E") with those listed by Lechner and Stone (Table "D") show that a large latitude must be allowed for the personal factor involved in the identification of a given pressure distribution with the more or less rigid pattern defined in the types.

A variation of type "D" is suggested by the authors which consists on the whole the same characteristics as defined by Lechner and Stone. This would occur as a transition from type C when the high over Alaska, Canada, and the

Carolinas has merged with the Bermuda high, and Tg and Tm air flow into the southeastern United States below the polar front.

An additional good weather type was discovered which had a frequency of occurrence that warranted its being classed among the weather types. It is given the designation Type E and is reproduced on Plate V.

The essential features of Type E are: (1) a low trough extending from the western Gulf northeastward to the eastern Great Lakes ending in an occlusion in the vicinity of Hudson Bay; (2) an extensive Bermuda high extending over southeastern United States; (3) a quasi-stationary front extending from W to E in the vicinity of Bermuda separating the Bermuda high from the re-enforcing transitional Pc air; (4) a polar continental high over the central and northwestern United States.

The percentages of cloudiness, winds, and weather are given in Table "E". It is apparent that Type E is generally a good weather type. The relatively high percentages of rain and fog in sectors 6 and 9 are due to wave motion on the quasi-stationary front in the vicinity of the Virginia Capes.

Carolinas has merged with the Bermuda High, and Cp and Ts air flow into the southeastern United States below the polar front.

An additional post-weather type was discovered which had a frequency of occurrence that warranted its being classed among the weather types. It is given the designation Type C and is reproduced as Plate 7.

The essential features of Type C are: (1) a low trough extending from the western Gulf northeastward to the eastern Great Lakes ending in an occlusion in the vicinity of Hudson Bay; (2) an extensive Bermuda High extending over southeastern United States; (3) a quasi-stationary front extending from W to E in the vicinity of Bermuda separating the Bermuda High from the re-curving transitional Tm air; (4) a polar continental high over the central and northwestern United States.

The percentages of visibilities, winds, and weather are given in Table 17. It is apparent that Type C is generally a good weather type. The relatively high percentages of rain and fog in sectors 4 and 5 are due to wave action on the quasi-stationary front in the vicinity of the Virginia Capes.

## V. ANALYSIS OF STATISTICAL DATA

The basis for using a partial index in this paper is the successful correlation of the partial index with the total index by members of the five-day forecasting staff at M.I.T. With this in mind, it is assumed that an index for the area chosen is indicative of the circulation in the relatively small area of the west Atlantic under consideration.

From an examination of the Continental and Continental-Pacific curves for three winters, Plates VI, VII, and VIII, it will be apparent that there is a good correlation. This might be expected, as the former area comprises 7/13 of the latter. This expected correlation was computed from the formula, $r_n = \frac{\sqrt{\Sigma C^2}}{\sqrt{\Sigma T^2}}$ , where $\Sigma$ indicates summations, C the values of the Continental Index, and T the values of the Continental-Pacific Index. The coefficient was found to be .685 for the three winters investigated. The actual correlation was computed from the usual formula for the correlation factor:

$$r = \frac{\Sigma(TC) - \frac{(\Sigma T)(\Sigma C)}{N}}{\sqrt{\left(\Sigma T^2 - \frac{(\Sigma T)^2}{N}\right)\left(\Sigma C^2 - \frac{(\Sigma C)^2}{N}\right)}}$$

where N indicates the total number of values used and other symbols as above. The resulting coefficient was found to be

.820 which is a relatively high factor in statistical experience.

From the above results one is able to determine the Continental-Pacific Index from the Continental Index, or to determine one index by means of the other, by use of this factor .820.

An interesting feature of the curves is the variation in periodicity and amplitude from year to year. The curve for 1932-33 shows that the periods were long and the amplitudes large, giving three maxima for the season. During the winter of 1938-39 the periods were short and the amplitude small with one exception. For 1940-41 the periods were moderate and the amplitudes moderate. Thus, if it is to be found that weather types occur in conjunction with specific values of zonal index or with trends of the zonal index, then the frequency of occurrence of types will vary from year to year.

As was stated in the introduction, the aim of this investigation was to find a means of forecasting the occurrence of a weather pattern or type by means of the zonal index. This might be done (1) if a certain zonal index value occurred concurrently with a certain weather type; (2) if a definite trend of the zonal index toward lower or toward higher values is associated with a certain weather type; (3) if the trend of the

zonal index indicates a transition from one weather type to another; and (4) if the variation of the five-day mean value from the yearly mean value can be identified with a certain weather type.

Plate XI is a graphic representation of the occurrence of values of zonal index for each weather type. As in each plate using block diagrams, the abscissae are values of zonal index in millibars and ordinates frequency of occurrence. By means of the method of first moments, it is possible to arrive at an approximate value of the median, but due to the values in which there were no occurrences, the use of a mean value of zonal index found by this means would be of questionable worth in forecasting of weather types. Scarcity of occurrence of types $A_2$ and D and the wide scattering in type E preclude the possibility of arriving at a representative mean value. The shape of the diagram for type $A_3$ suggests two medians, one at about -3 millibars and one at about + 7 millibars.

In a manner somewhat analogous to the analysis of a barograph trace the curves of zonal indices were analyzed with respect to the occurrence of weather types in an attempt to discover some connection between trends of the zonal index and the weather types. The results are shown in Table "B". Again in the cases of types $A_2$ and D, there are insufficient

occurrences to arrive at any conclusions, while in the case of types $A_3$ and C, which have the greatest frequencies, there are roughly twice as many occurrences under definite falling as under definite rising tendencies. Were these the only tendencies to be dealt with, a forecast might be made with fair success; but the scattering of tendencies as shown in Table "B" render forecasting more or less a matter of guesswork when forecasting on tendencies only.

A study of Table "A" in connection with the curves of zonal indices affords no thumb rule as to forecasting transition from one weather type to another by means of the trend of zonal index. On the whole, the type occurrence is spasmodic, except in the case of type $A_3$ which appears often as a transition from type C. However, the trend is not indicative, as in some cases it was rising from C towards $A_3$ and in other cases falling.

The results of the investigation of the fourth possibility of connecting zonal index with weather type occurrence are shown in Plates IX and X. The former is a plot of frequency of occurrence of departure from the yearly mean of zonal index for each type. The latter is a similar plot using the departures from the mean of the three seasons investigated. The two diagrams differ slightly because of the low mean index of

5.7 millibars for the year 1940-41 as compared to 10.0 and 12.0 millibars for 1932-33 and 1938-39 respectively, but for the analysis they may be considered similar. As in the case of the plotted values of zonal index, again by the method of moments approximate medians may be computed. In the block diagrams for types $A_3$ and C, this process gives values which are even less reliable than those obtained from the diagrams plotted for actual zonal index because of the more erratic distribution of frequency. For the other types, lack of data and wide scattering allow no definite conclusions to be drawn.

## VI. SUMMARY AND CONCLUSIONS

The statistical analysis has shown that the correlation is poor between the Continental or Continental-Pacific Zonal Index and the weather types in the western North Atlantic. Such a finding is not consistent with the results obtained in the five-day forecast project at M.I.T. The discrepancy may be explained by the fact that five-day mean pressure charts are used by the five-day forecasters, whereas in this paper an attempt was made to correlate the zonal index with daily pressure maps. The minor perturbations caused by topography over the eastern portion of North America are not smoothed out as is accomplished by a five-day mean pressure map. Also, the area covered by the type patterns is relatively so small that

the circulation is only a small part of that represented by the zonal index and in this particular area is broken up by the minor perturbations as they move off the continent.

The rough means of zonal index and rough means of departure from the mean zonal index found for each type occurrence, though not to be considered reliable for purposes of forecasting, still show that there is a connection between zonal index and pressure distribution. Further research covering many winters and with a rigid adherence to the criteria of the pressure types should result in reliable values of zonal index as an indication of type occurrence. However, such indications will be useless when a pressure distribution varies slightly from the rigid criteria. The authors found it impossible to hold to rigid criteria in scanning the maps because of the scarcity of occurrence of types under these conditions. It is believed that in the block diagrams of this paper, the number of type maps which loosely fit the criteria outweigh those which fit the criteria more exactly and thus the correlation of a definite type is hidden.

The authors were unable to obtain the percentages of occurrence and the persistencies found by Lackner and Stone. It is evident that the personal factor involved in type identification renders forecasting by this method a matter of personal opinion.

TABLE "A" TYPE CLASSIFICATION

1932-33

| | | |
|---|---|---|
| Dec. | 1 | B |
| | 2 | B |
| | 3 | C |
| | 4 | E |
| | 5 | C |
| | 6 | C |
| | 7 | E |
| | 12 | E |
| | 14 | A1 |
| | 15 | C |
| | 17 | B |
| | 18 | B |
| | 23 | E |
| | 25 | E |
| | 26 | C |
| | 28 | C |
| Jan. | 1 | B |
| | 5 | C |
| | 6 | C |
| | 7 | C |
| | 8 | C |
| | 10 | C |
| | 11 | C |
| | 12 | A3 |
| | 13 | A3 |
| | 16 | C |
| | 17 | C |
| | 18 | C |
| | 19 | E |
| | 20 | C |
| | 21 | C |
| | 22 | E |
| | 25 | E |
| | 28 | A3 |
| | 29 | A3 |
| | 30 | A3 |
| Feb. | 1 | E |
| | 6 | A1 |
| | 7 | E |
| | 9 | A1 |
| | 15 | C |
| | 16 | C |
| | 19 | B |
| | 20 | E |
| | 22 | D |
| | 23 | E |
| | 25 | E |
| | 26 | A3 |
| | 27 | A3 |

1939

| | | |
|---|---|---|
| Jan. | 1 | C |
| | 2 | C |
| | 3 | C |
| | 4 | A3 |
| | 5 | E |
| | 6 | D |
| | 8 | C |
| | 9 | E |
| | 10 | A3 |
| | 11 | A3 |
| | 12 | A3 |
| | 16 | A3 |
| | 17 | A3 |
| | 21 | A1 |
| | 22 | A3 |
| | 23 | D |
| | 25 | A3 |
| | 27 | C |
| | 28 | C |
| | 29 | C |
| | 31 | A3 |
| Feb. | 1 | A3 |
| | 2 | E |
| | 4 | A3 |
| | 7 | A3 |
| | 9 | C |
| | 10 | E |
| | 12 | A1 |
| | 13 | C |
| | 15 | A3 |
| | 16 | D |
| | 18 | C |
| | 19 | C |
| | 20 | B |
| | 21 | A2 |
| | 22 | A3 |
| | 23 | A1 |
| | 24 | C |
| | 25 | A2 |
| | 26 | A3 |
| | 27 | A3 |
| Mar. | 1 | A1 |
| | 2 | B |
| | 3 | B |
| | 5 | C |
| | 6 | A3 |
| | 7 | A3 |
| | 8 | A3 |
| | 10 | A3 |

1940-41

| | | |
|---|---|---|
| Nov. | 20 | C |
| | 21 | E |
| | 22 | C |
| | 23 | C |
| | 24 | C |
| | 25 | A3 |
| | 26 | E |
| | 27 | A3 |
| | 28 | A3 |
| | 30 | C |
| Dec. | 1 | A3 |
| | 5 | C |
| | 6 | A3 |
| | 7 | E |
| | 9 | A1 |
| | 10 | C |
| | 13 | C |
| | 16 | E |
| | 18 | D |
| Jan. | 5 | A3 |
| | 11 | A3 |
| | 13 | A3 |
| | 18 | A2 |
| | 20 | A1 |
| | 21 | D |
| | 23 | C |
| | 24 | C |
| | 25 | C |
| | 26 | A3 |
| | 29 | D |
| Feb. | 3 | A2 |
| | 9 | A3 |
| | 10 | B |
| | 12 | B |
| | 13 | E |
| | 15 | A3 |
| | 16 | A1 |
| | 18 | A3 |
| | 19 | A3 |
| | 20 | A3 |
| | 21 | A3 |
| | 22 | A3 |
| | 23 | A3 |

TABLE B

<u>Classification Vs. Tendencies</u>

| TYPE / TENDENCY | $A_1$ | $A_2$ | $A_3$ | B | C | D | E |
|---|---|---|---|---|---|---|---|
| | 6 | 1 | 9 | 5 | 9 | 3 | 9 |
| | 1 | | 2 | | | | |
| | | 2 | 1 | 1 | 2 | | 2 |
| | | | 2 | | 2 | | |
| | 1 | | 20 | 2 | 21 | 2 | 5 |
| | | 1 | 3 | | 4 | | 3 |
| | | | 1 | 1 | 1 | 1 | 1 |
| | | | 1 | 1 | | | |
| | | 1 | 2 | 1 | 2 | | 2 |

## T A B L E "C"

Table of Frequencies and Persistencies as found by Authors

---

$A_1$ 4% occurrence
1 day duration 100%

$A_2$ 2% occurrence
1 day duration 100%

$A_3$ 17% occurrence
1 day duration 43%
2 days duration 32%
3 days duration 24%
6 days duration 1%

B. 4% occurrence
1 day duration 45%
2 days duration 55%

C. 17% occurrence
1 day duration 33%
2 days duration 23%
3 days duration 35%
4 days duration 9%

D. 3% occurrence
1 day duration 100%

E. 9% occurrence
1 day duration 100%

---

## T A B L E "D"

Table of Frequencies and Persistencies as found by Lackner and Stone.

---

$A_1$ 10% occurrence
1 day duration 21%
2 days duration 50%
3 days duration 22%
4 days duration 7%

---

$A_2$ 6% occurrence
2 days duration 40%
3 days duration 60%

---

$A_3$ 9% occurrence
1 day duration 15%
2 days duration 69%
3 days duration 16%

---

B. 10% occurrence
1 day duration 0%
2 days duration 37%
3 days duration 27%
4 days duration 27%
5 days duration 9%

---

C. 9% occurrence

2 days duration 64%
3 days duration 27%
4 days duration 9%

---

D. 12% occurrence
1 day duration 12%
2 day duration 44%
3 days duration 25%
4 days duration 19%

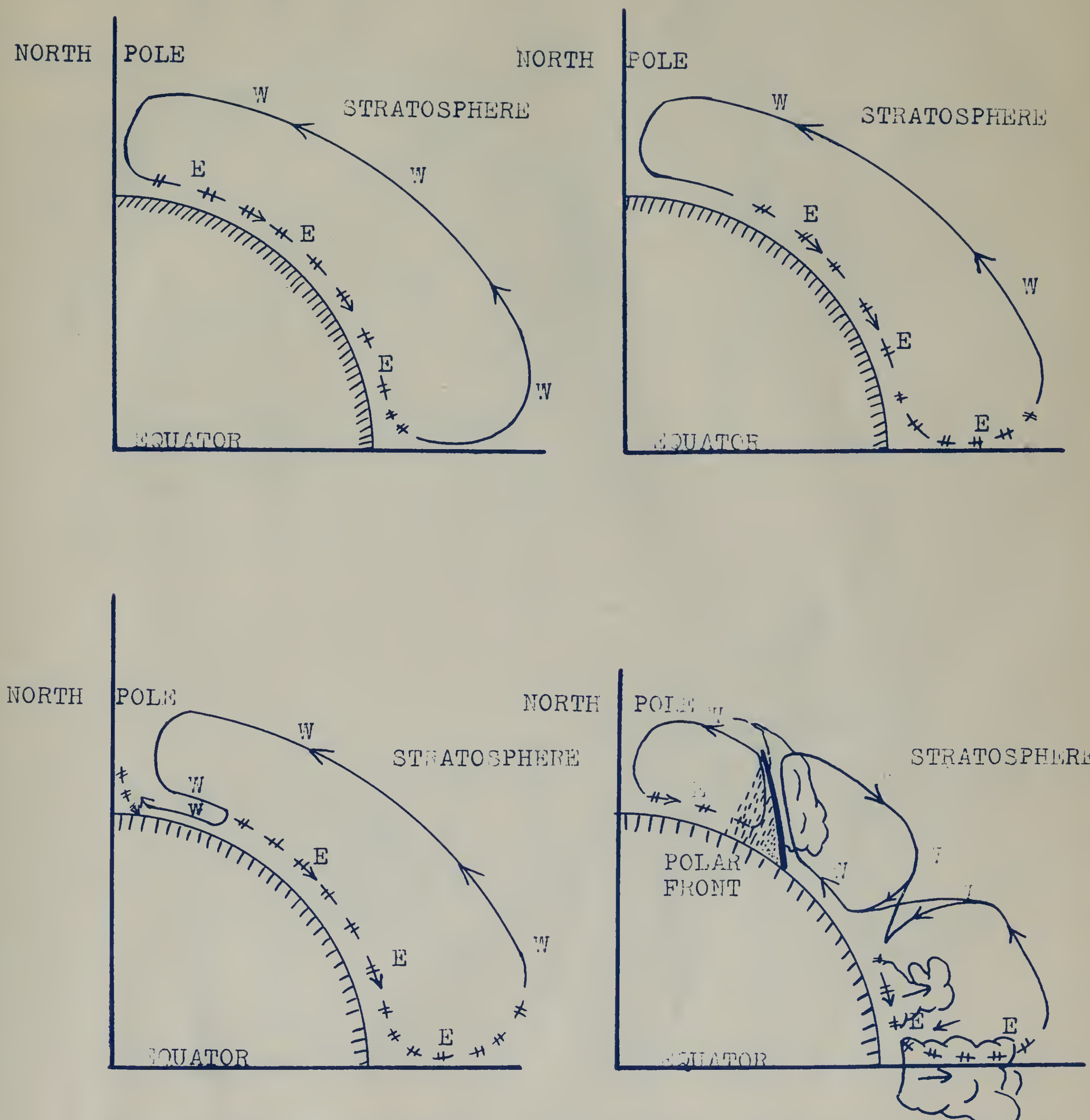
---

## T A B L E "E"

Type E

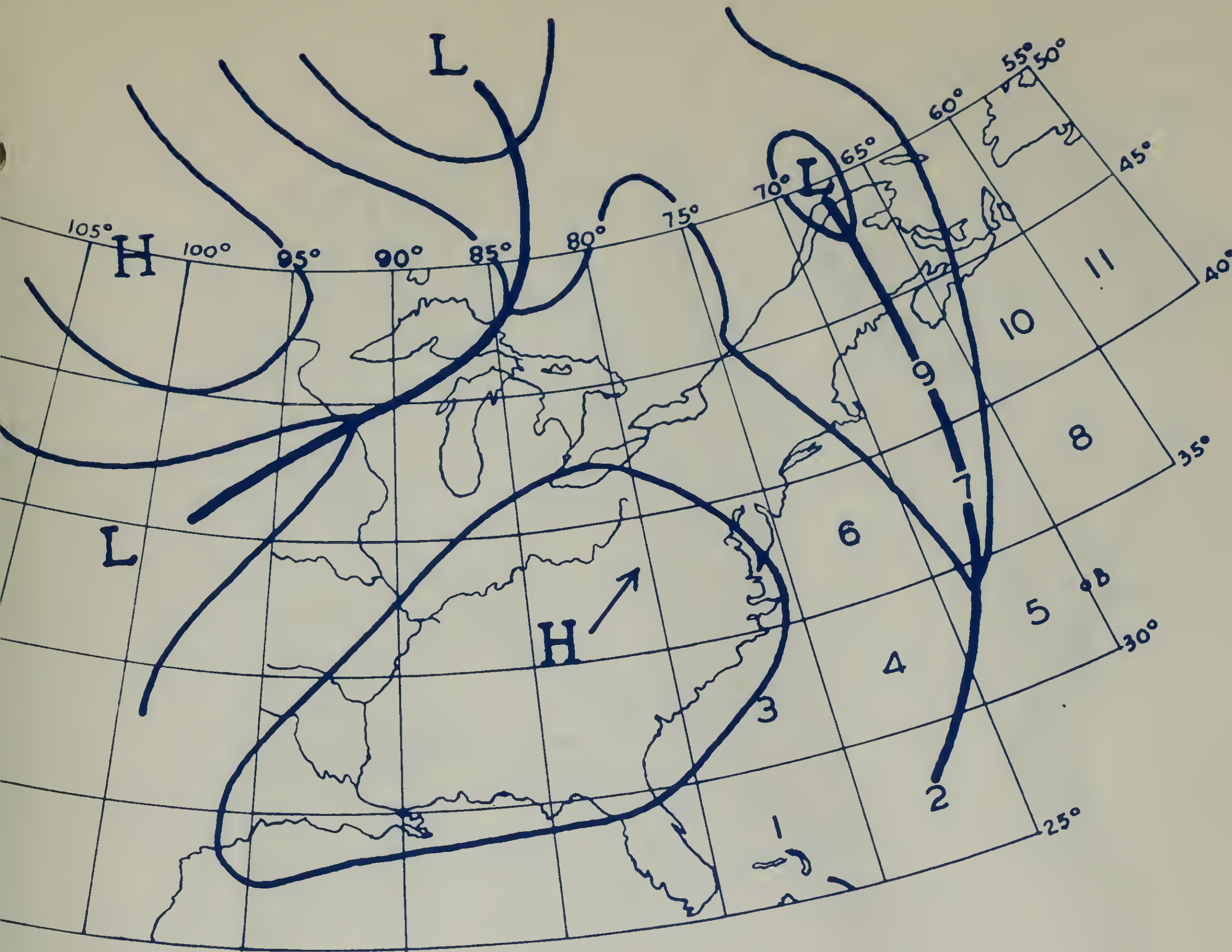
| | Sector | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | [illegible] | 6 | 7 | 8 | 9 | 10 | 11 |
| No. Obs. | 51 | 41 | 78 | 38 | 10 | 19 | 58 | 25 | 13 | 75 | 45 | 28 |
| % Cloudiness | | | | | | | | | | | | |
| Clear | 15 | 7 | 5 | 21 | 0 | 16 | 7 | 4 | 8 | 21 | 13 | 7 |
| Scattered | 40 | 42 | 16 | 34 | 20 | 21 | 7 | 16 | 0 | 12 | 11 | 11 |
| Broken | 33 | 44 | 40 | 37 | 70 | 63 | 38 | 48 | 38 | 16 | 36 | 46 |
| Overcast | 12 | 7 | 39 | 8 | 10 | 0 | 48 | 32 | 54 | 51 | 40 | 36 |
| % Winds | | | | | | | | | | | | |
| 0-3 | 80 | 76 | 65 | 66 | 80 | 26 | 54 | 60 | 23 | 57 | 30 | 23 |
| 4-5 | 20 | 24 | 35 | 32 | 20 | 58 | 41 | 36 | 23 | 35 | 38 | 31 |
| 6-7 | 0 | 0 | 0 | 2 | 0 | 11 | 5 | 4 | 46 | 8 | 26 | 38 |
| 8 & above | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 8 | 0 | 6 | 8 |
| % Weather | | | | | | | | | | | | |
| Rain | 0 | 0 | 10 | 0 | 0 | 5 | 12 | 0 | 0 | 9 | 4 | 3 |
| Showers | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 3 | 7 | 3 |
| Drizzle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| Fog | 0 | 0 | 9 | 0 | 0 | 0 | 14 | 0 | 0 | 8 | 0 | 7 |
| Thunderstorm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Squally | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 15 | 0 | 2 | 3 |
| Snow | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 7 |
| Hail | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

PLATE NO. I

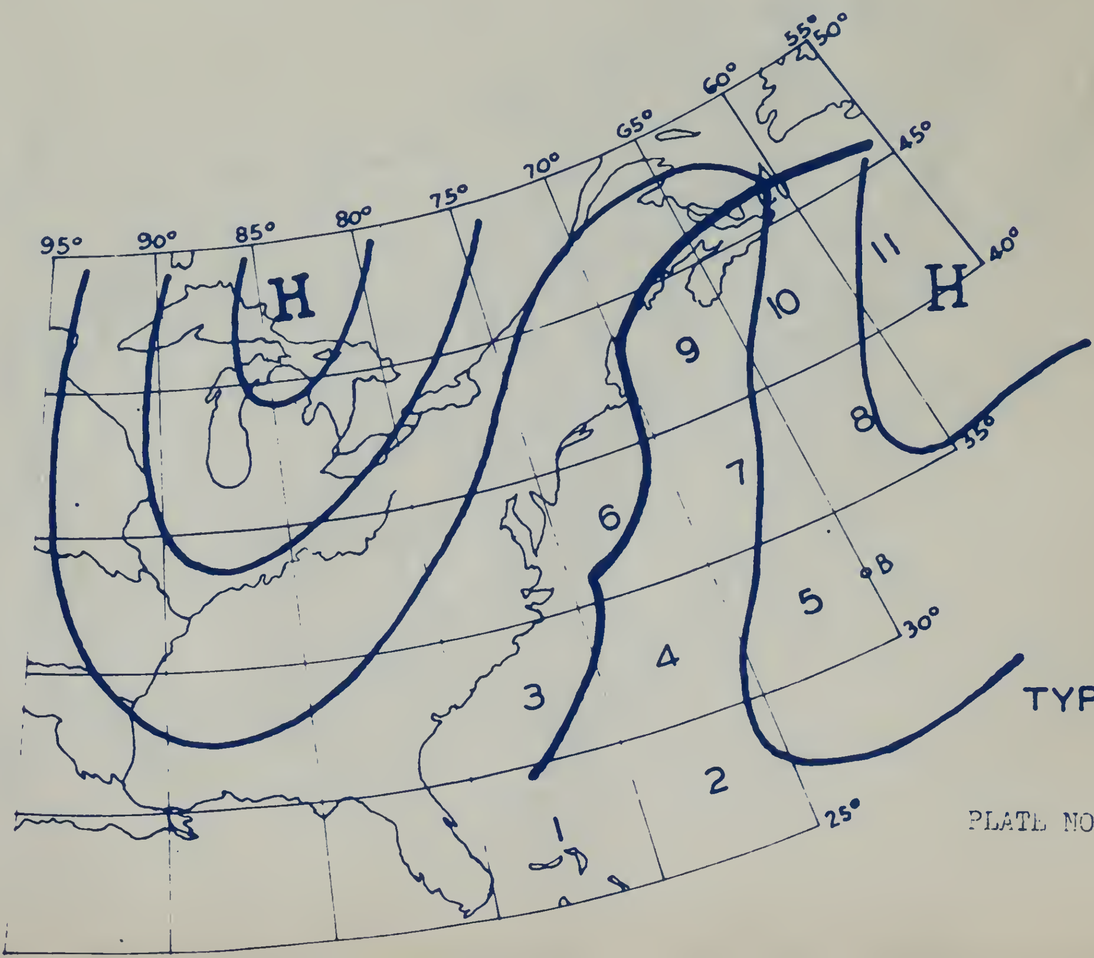



Dynamics of the Breakdown of Meridional Circulation under the Influence of the Earth's Rotation and of Surface Friction.

(From Notes on the General Circulation of the Atmosphere by C.G. ROSSBY.)



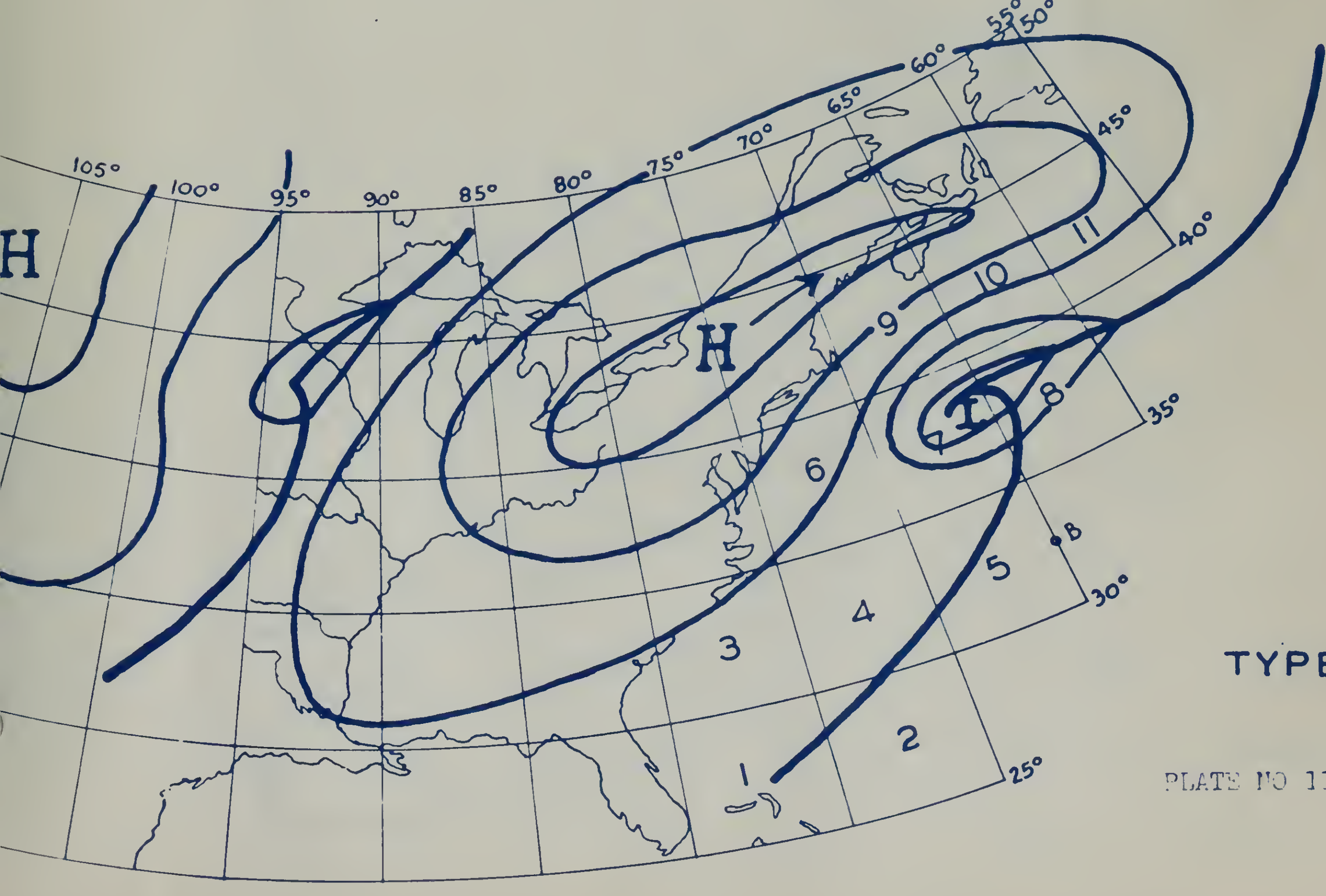

TYPE A₁




TYPE A₂

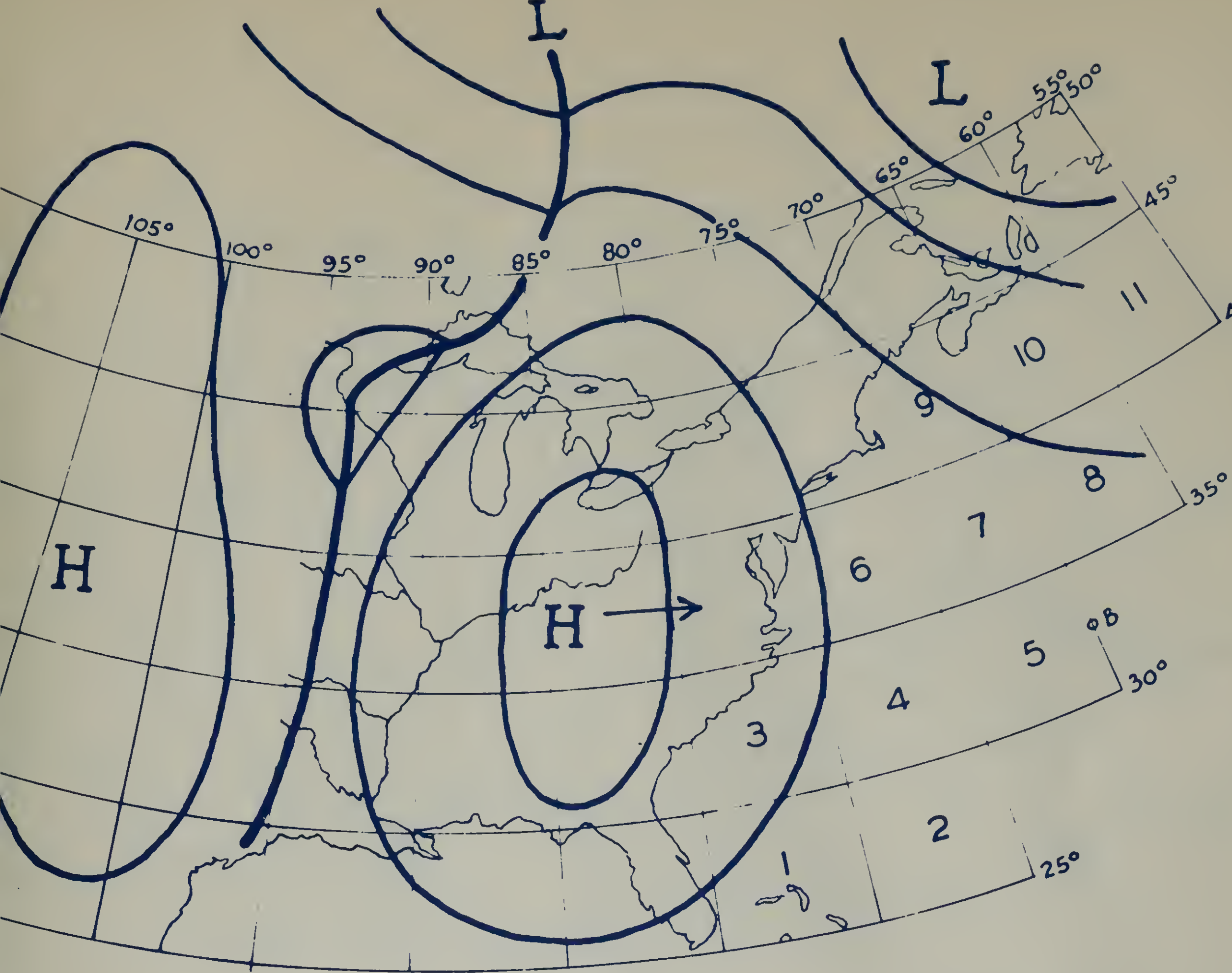
PLATE NO 11


TYPE $A_3$

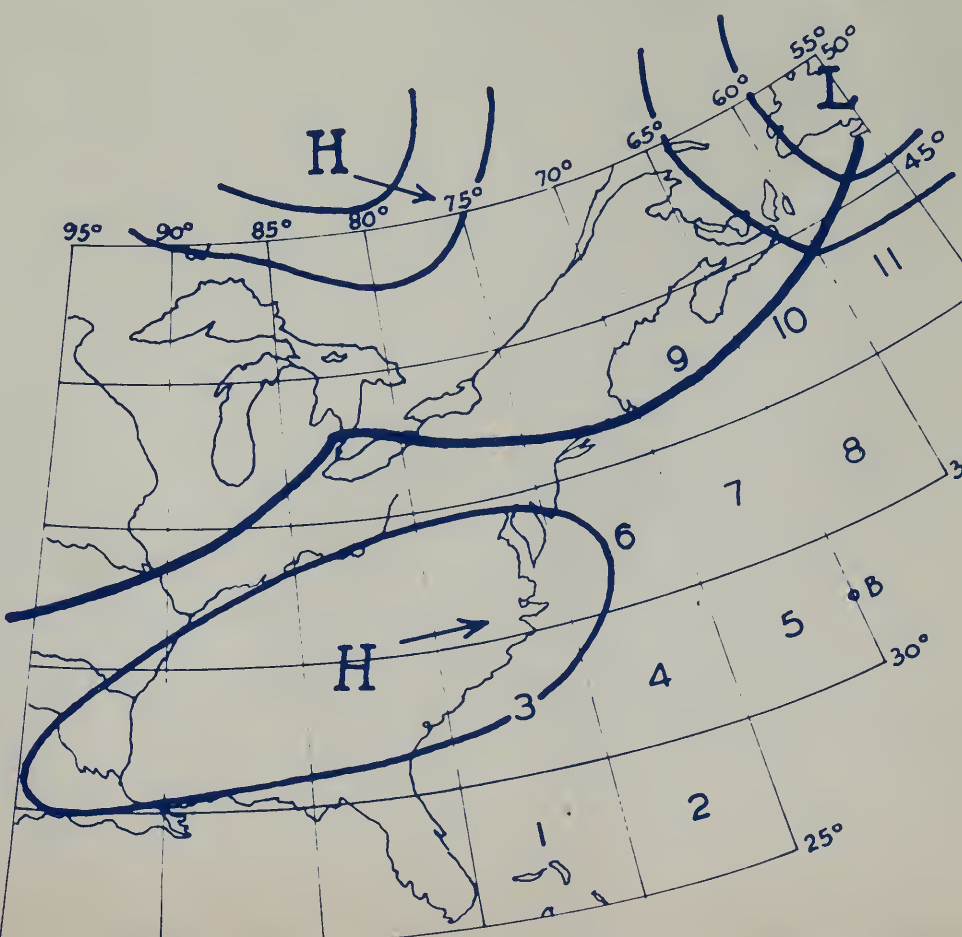



TYPE B

PLATE NO 111

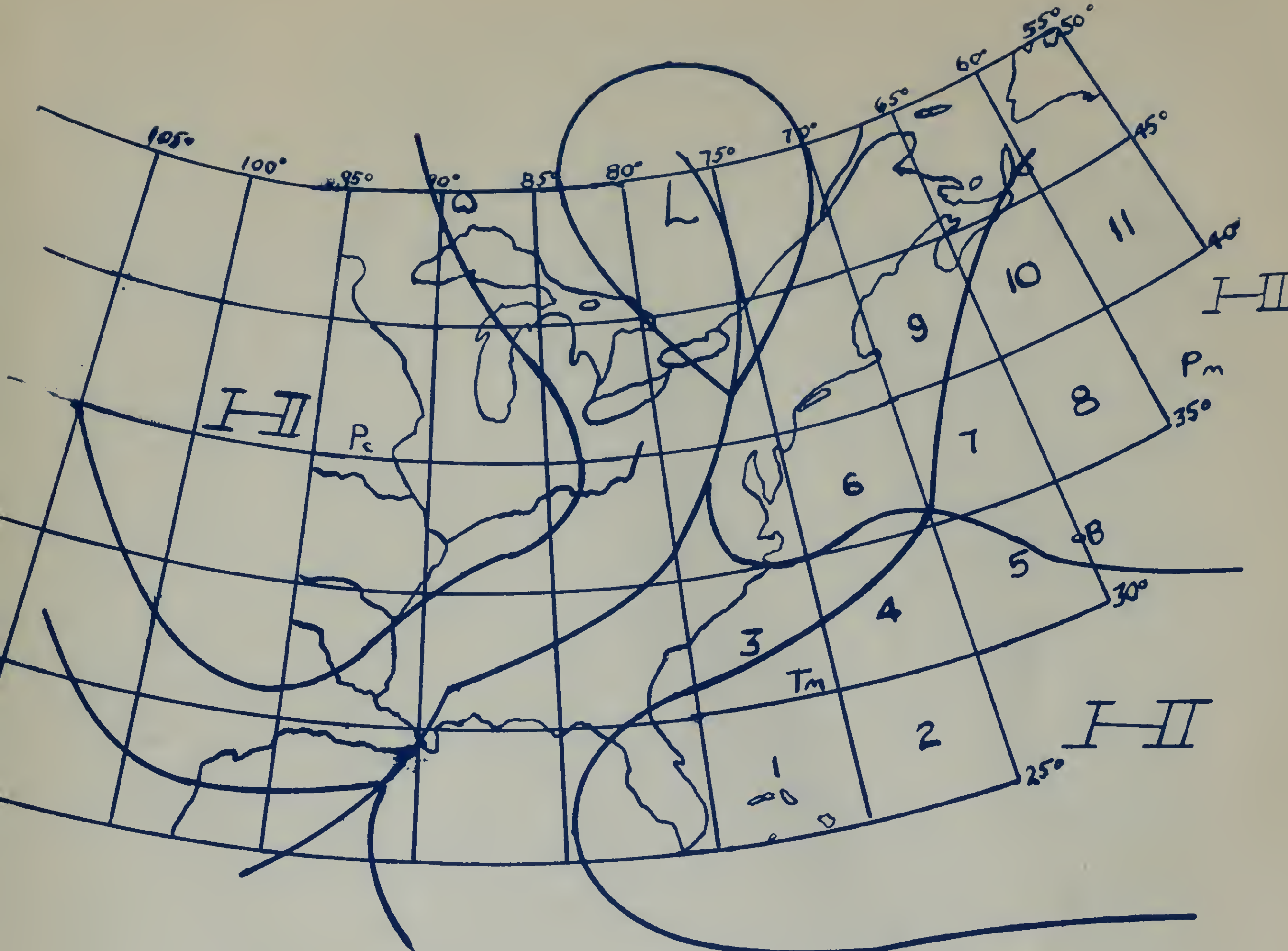



TYPE D




TYPE C

PLATE NO IV




TYPE "E".

PLATE NO V

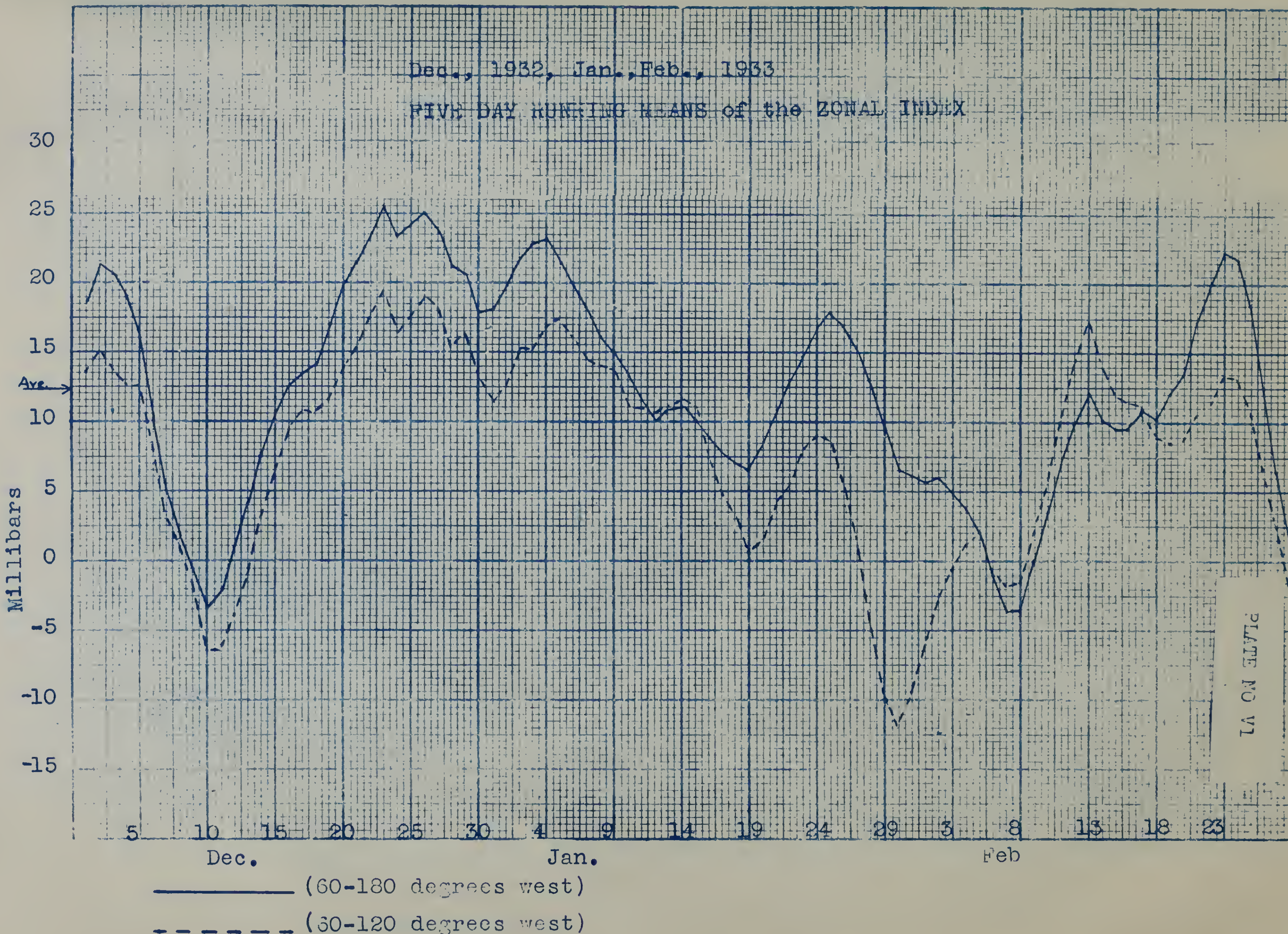
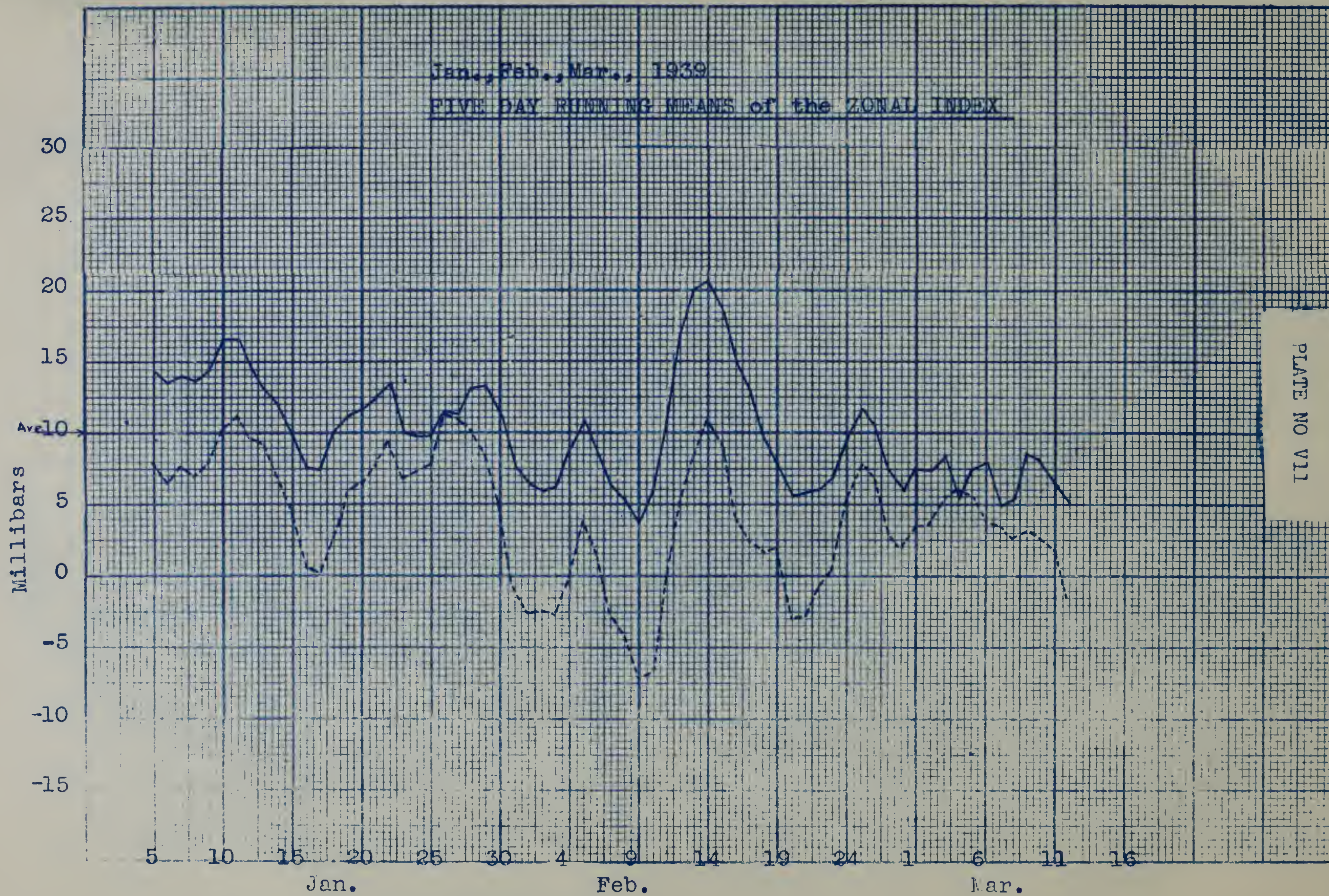


PLATE NO VI
Dec., 1932, Jan.,Feb., 1933
FIVE DAY RUNNING MEANS of the ZONAL INDEX
Millibars
30
25
20
15
Ave.
10
5
0
-5
-10
-15
5
10
15
20
25
30
4
9
14
19
24
29
3
8
13
18
23
Dec.
Jan.
Feb
(60-180 degrees west)
(30-120 degrees west)

PLATE NO V11




——————— (60-180 degrees west)

- - - - - - - - - - (60-120 degrees west)

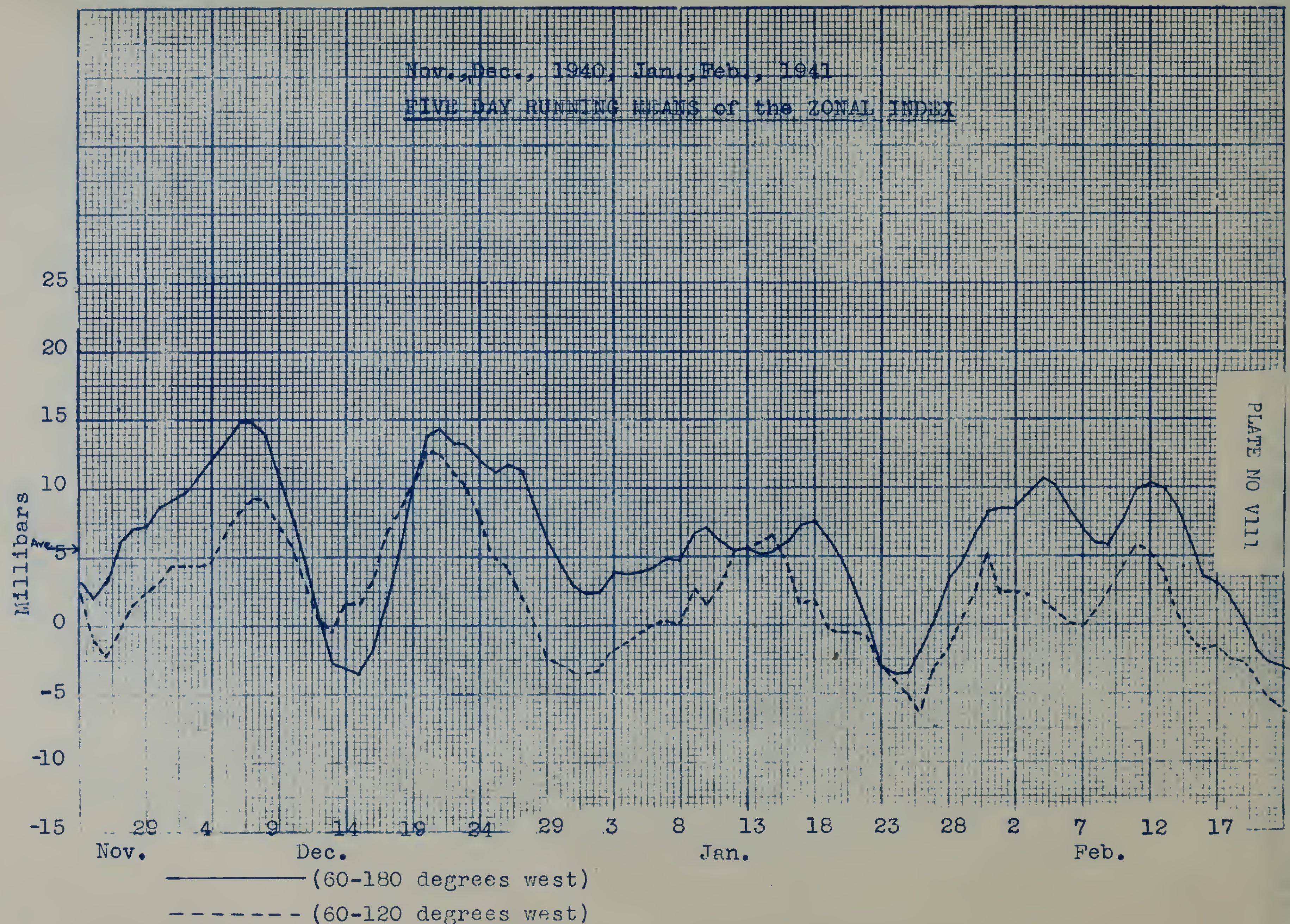


PLATE NO V111
Nov., Dec., 1940, Jan., Feb., 1941
FIVE DAY RUNNING MEANS of the ZONAL INDEX
Millibars
25
20
15
10
Ave. 5
0
-5
-10
-15
29
4
9
14
19
24
29
3
8
13
18
23
28
2
7
12
17
Nov.
Dec.
Jan.
Feb.
(60-180 degrees west)
(60-120 degrees west)

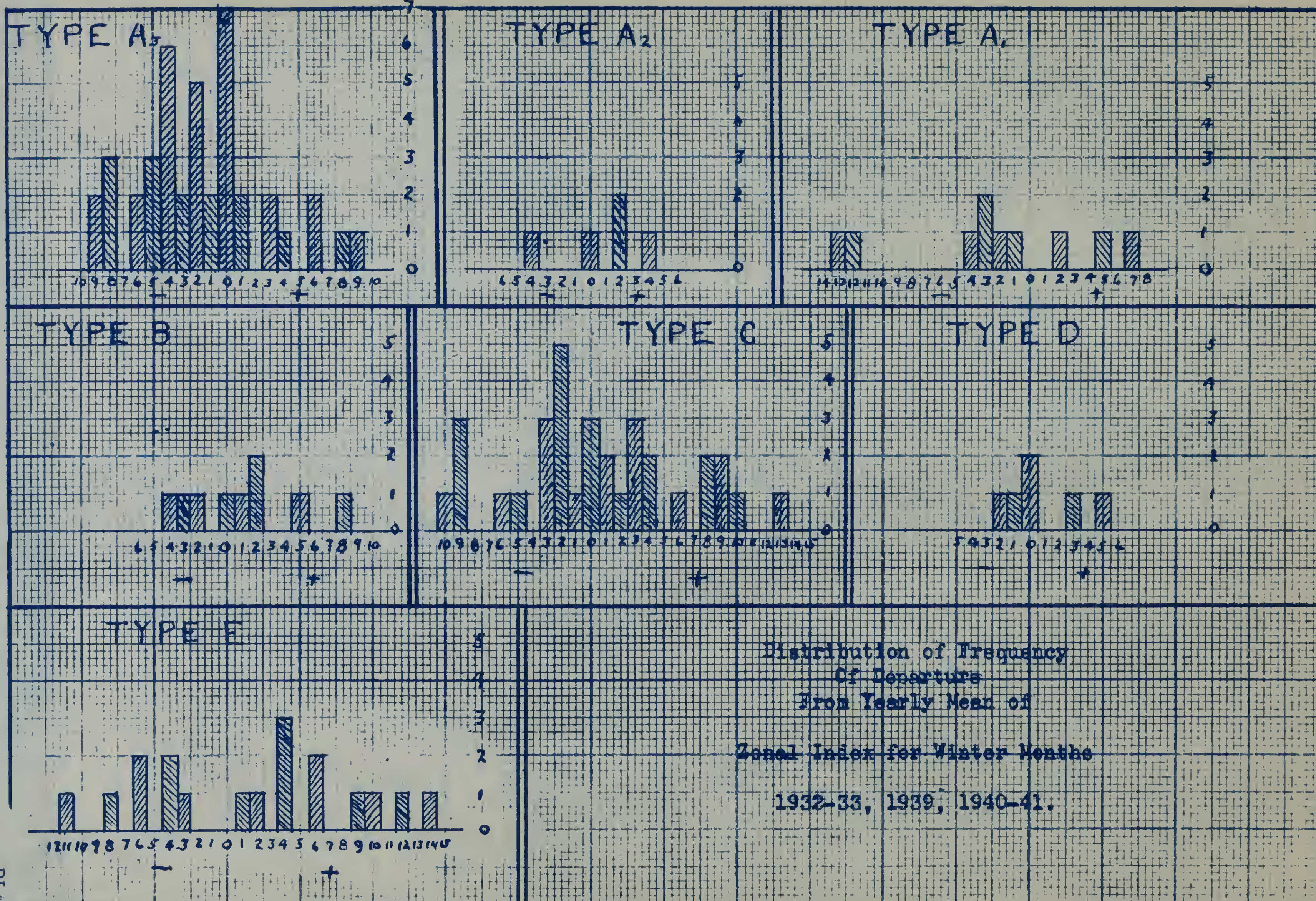

TYPE A₃
TYPE A₂
TYPE A₁
TYPE B
TYPE C
TYPE D
TYPE E
Distribution of Frequency
Of Departure
From Yearly Mean of
Zonal Index for Winter Months
1932-33, 1939, 1940-41.

PLATE NO IX


Distribution of Frequency of Departure
from Three-year Mean of Zonal Index for
Winter Months 1932-33, 1939, 1940-41

PLATE NO X

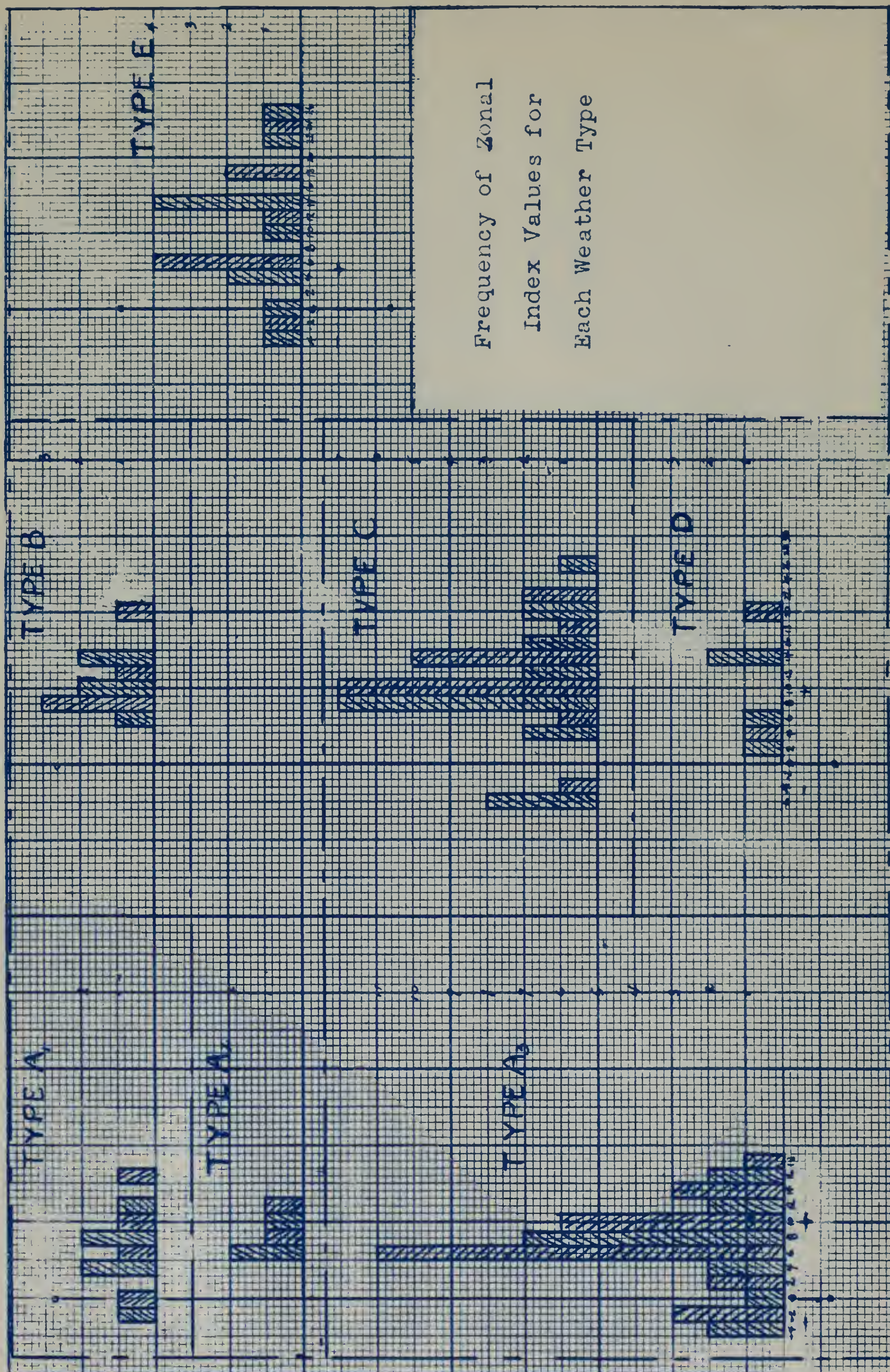

Frequency of Zonal
Index Values for
Each Weather Type
TYPE A₁
TYPE A₂
TYPE A₃
TYPE B
TYPE C
TYPE D
TYPE E

PLATE NO X1